BIOMASS-TO-ETHANOL CONVERSION TECHNOLOGY CHARACTERIZATION

Submitted to:

National Renewable Energy Laboratory
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Submitted by:

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Name of system characterized: Biomass-to-Ethanol Conversion

Line 1. SYSTEM OVERVIEW:

a. System schematic, system boundary, inputs, and outputs

Exhibit 1 below illustrates the schematic of the Biomass-to-Ethanol Conversion system (area within the box). Input requirements consist primarily of feedstock sources from biomass which include the cellulosic/organic portions of municipal solid wastes (MSW), agricultural residues (AR), herbaceous energy crops (HEC), and short rotation woody crops (SRWC). In addition to the biomass feedstock, the process requires the use of chemicals, enzymes and water to break down the biomass into sugars for fermentation. While the system requires steam for process heat, it is generated from unused portions of the biomass. The overall efficiency of this process generates enough steam to meet its needs, as well as provide surplus steam to generate electricity for the plant and to sell to the local power grid. The surplus electricity is one of the main outputs of the process. The final product from this process is ethanol, which can be used in dedicated and flexible fuel vehicles, as a reformulated blending component in gasoline, or as a feedstock for ETBE (ethyl tertiary butyl ether) a highly-valued reformulated gasoline component. Other outputs include water effluents and air releases.

b. System description

As shown in Exhibit 1, the biomass-to-ethanol conversion system requires the inputs of the biomass as well as chemicals and enzymes to breakdown the biomass feedstock into its cellulosic components. As a result of this process, the cellulose and xylose (converted from hemicellulose) fractions of the biomass are sent to saccharification and fermentation, where they are hydrolyzed into sugars and fermented into ethanol. The remaining lignin fraction is sent to the boiler to generate heat and electricity. The technical distinguishing factors between this process and the conventional corn-to-ethanol process is that the biomass-to-ethanol conversion presented above uses enzymes and simultaneous saccharification and fermentation (SSF), while grain-to-ethanol uses sulfuric acids and separated hydrolysis and fermentation (SHF). In practical terms, this process, besides being more process efficient, obtains higher ethanol yields because it uses greater portions of the biomass feedstock. Conventional grain-to-ethanol systems only convert the starchy portions of the feedstock, and leave the cellulosic fractions. From the SSF, the ethanol "beer" is sent to a distillation column where the ethanol is separated from the water to a purity level of 95 % ethanol, 5% water.

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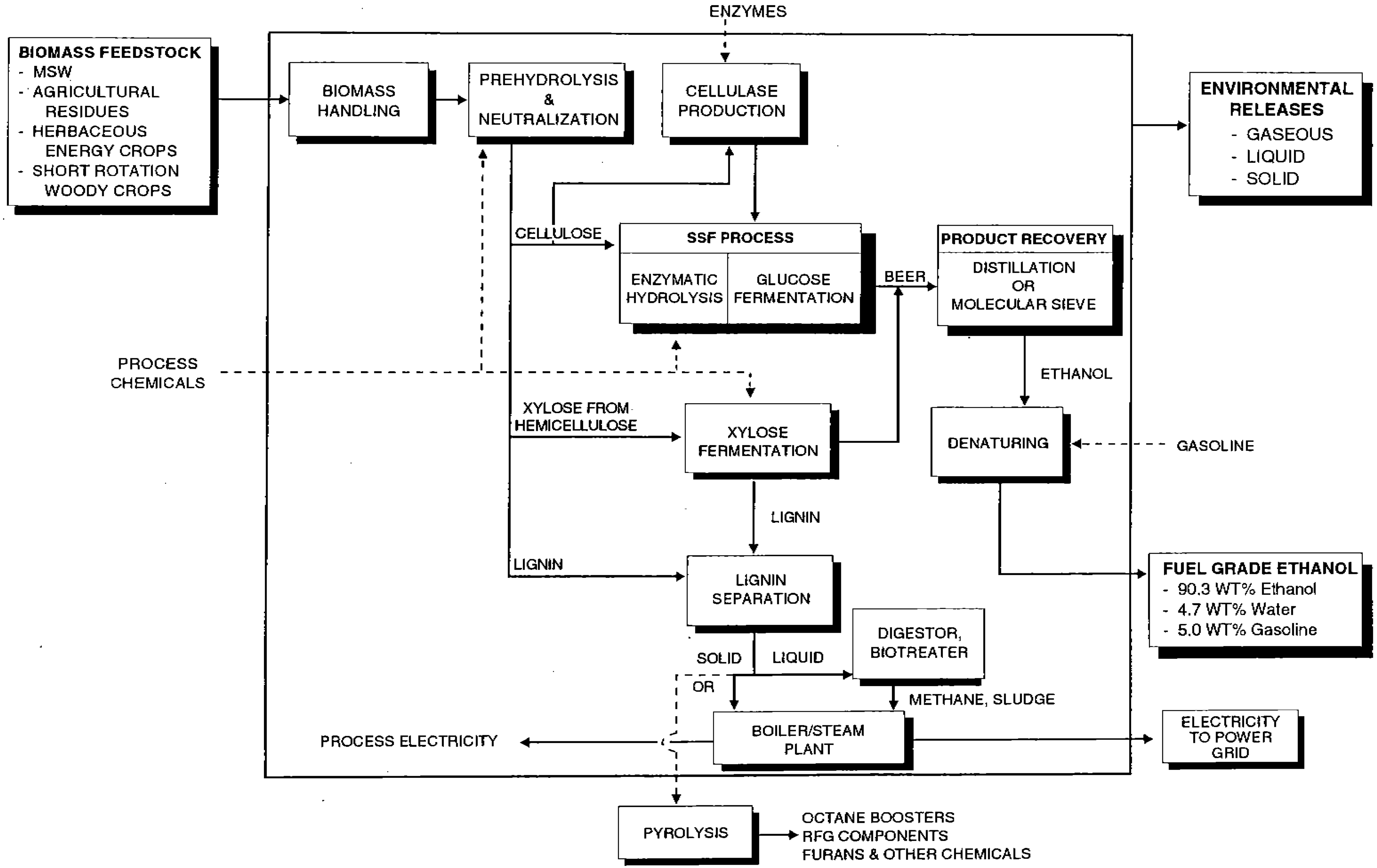
Exhibit 1
Block Flow Diagram
Biomass-to-Ethanol Conversion Process



SOURCE: BIOFUELS SYSTEMS DIVISION - U.S. DEPARTMENT OF ENERGY AND NATIONAL RENEWABLE ENERGY LABORATORY

Biomass-to-Ethanol Conversion

Progress in the development of the biomass-to-ethanol conversion process has achieved significant reductions in the expected cost of ethanol production as shown in Exhibit 2. Since 1980, R&D technological achievements sponsored by DOE have reduced the projected cost of ethanol from $3.60/gallon to an estimated $1.22/ gallon in 1993. Several on-going research activities are expected to reduce this price by almost half over the next 6-10 years. More detailed information about the anticipated technological and economical breakthroughs are mentioned in Line 1-g (Exhibit 4).

This technology characterization relies on models developed for use in the *Assessment of Biomass Variability, Biomass Conversion, and Ethanol Use* prepared for the Department of Energy by Meridian Corporation. Notation in the text to "the model" refers to this publication.

c. **The system characterized is:** Representative ☒, Best Present ☐, Best Future ☐, A Composite ☐, An Average ☐:

d. **The system characterized is located in a:** Representative Region ☒, Best Region ☐, National Average Location ☐:

The information used in this technology characterization is based on the U.S. being split into five regions as shown in Exhibit 3. The usage of each biomass feedstock class (MSW, AR, HEC, and SRWC) will be explained in the scenario section (Line 3b) below. The representative region and biomass composition for each of these biomass classes are as follows:

MSW = National Average (composition is primarily the same for all regions)
AR = Southeast/South Central region
HEC = North Central region
SRWC = Pacific Coast region

Biomass Feedstock Composition (% wt)	MSW	AR	HEC	SRWC
Cellulose	45.50	34.67	30.15	48.78
Hemicellulose	8.50	2.44	31.77	18.78
Lignin	10.00	10.21	6.42	26.24
Ash	15.00	0.00	3.69	1.63
N.S. Carbohydrates	8.50	0.00	0.00	3.20
Crude Protein	3.30	0.00	9.07	0.50
Extractives	6.70	3.65	5.68	0.86
Soluble Solids	2.50	49.02	13.23	0.00

Exhibit 2
Historical Process Cost Reductions Chart

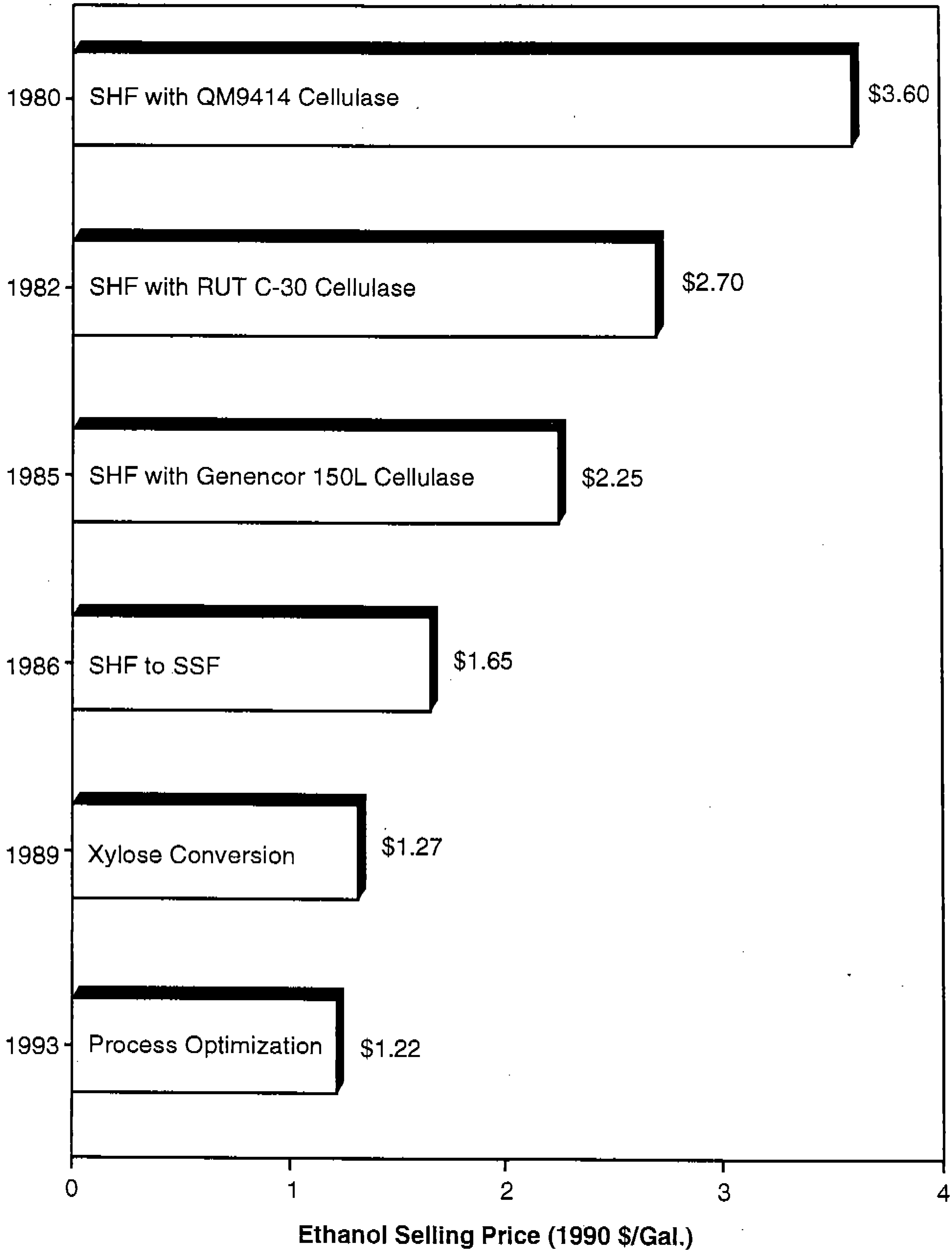
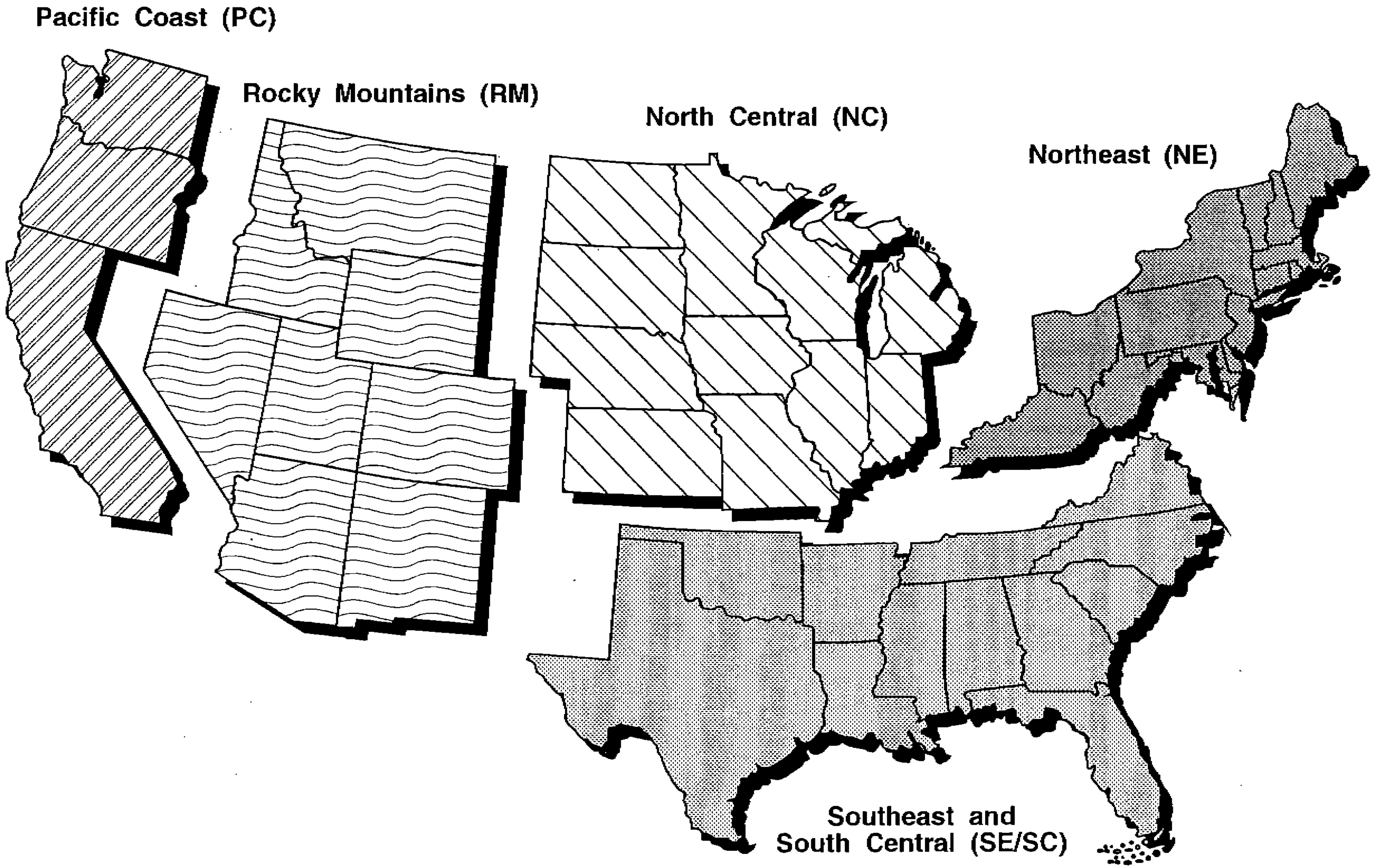


Exhibit 3
Regions Used by the Biomass Feedstock Variability Model



Biomass-to-Ethanol Conversion

e. **Alternative System Name:** Refinery Processing of Crude Oil to Gasoline

The ultimate goal of developing biomass-ethanol is to provide a clean, energy efficient transportation fuel that reduces U.S. reliance on imported petroleum. Because biomass-ethanol is produced from different feedstocks having different processing requirements and products than crude oil, the biomass-to-ethanol conversion process cannot completely substitute for a petroleum refinery or vice versa. However, the energy requirements, emissions, infrastructure and delivery costs to the consumer can be analyzed in a systematic approach as was performed in the Total Fuel Cycle Analysis.[1] Additionally, the biomass-to-ethanol conversion process generates surplus electricity that can be used as an electricity generation source. This attractive process byproduct might be comparable with other conventional technologies (i.e., coal, natural gas, photovoltaics) in the future.

f. **State of Technological maturity of the System:** Conceptual ☐, R&D ☒, Engineering Development ☐, Near Commercial ☐, Commercially Available ☐, Mature ☐:

This technology is in the preliminary phases of verifying laboratory results achieved at the bench-scale level. Within the next 1-2 years a fully operational process development unit (PDU) will exist bringing the technology into the engineering development phase.

g. **Expected time to commercial availability (years):** Currently Available ☐, 1-5 ☐, 6-10 ☒, 11-15 ☐, 16-20 ☐:

Due to recent environmental legislative initiatives such as the 1990 Clean Air Act Amendments (CAAA) and the Energy Policy Act of 1992, there is a lot of interest in the use of ethanol. The main technoeconomic barrier is the current cost of biomass-ethanol. This price of $1.22 is not currently competitive with gasoline prices, although it may be competitive as an oxygenate, an octane booster, and/or a component for reformulated gasoline (RFG).

To achieve the program goal of producing biomass-ethanol at $0.70/gallon, technology developments need to occur in four major process areas:

1) Pretreatment;
2) Hemicellulose Conversion (Xylose);
3) Cellulose Conversion; and
4) Feedstock Production and Collection.

Exhibit 4 provides specific goals to improve the efficiency and costs of each of these four process areas.

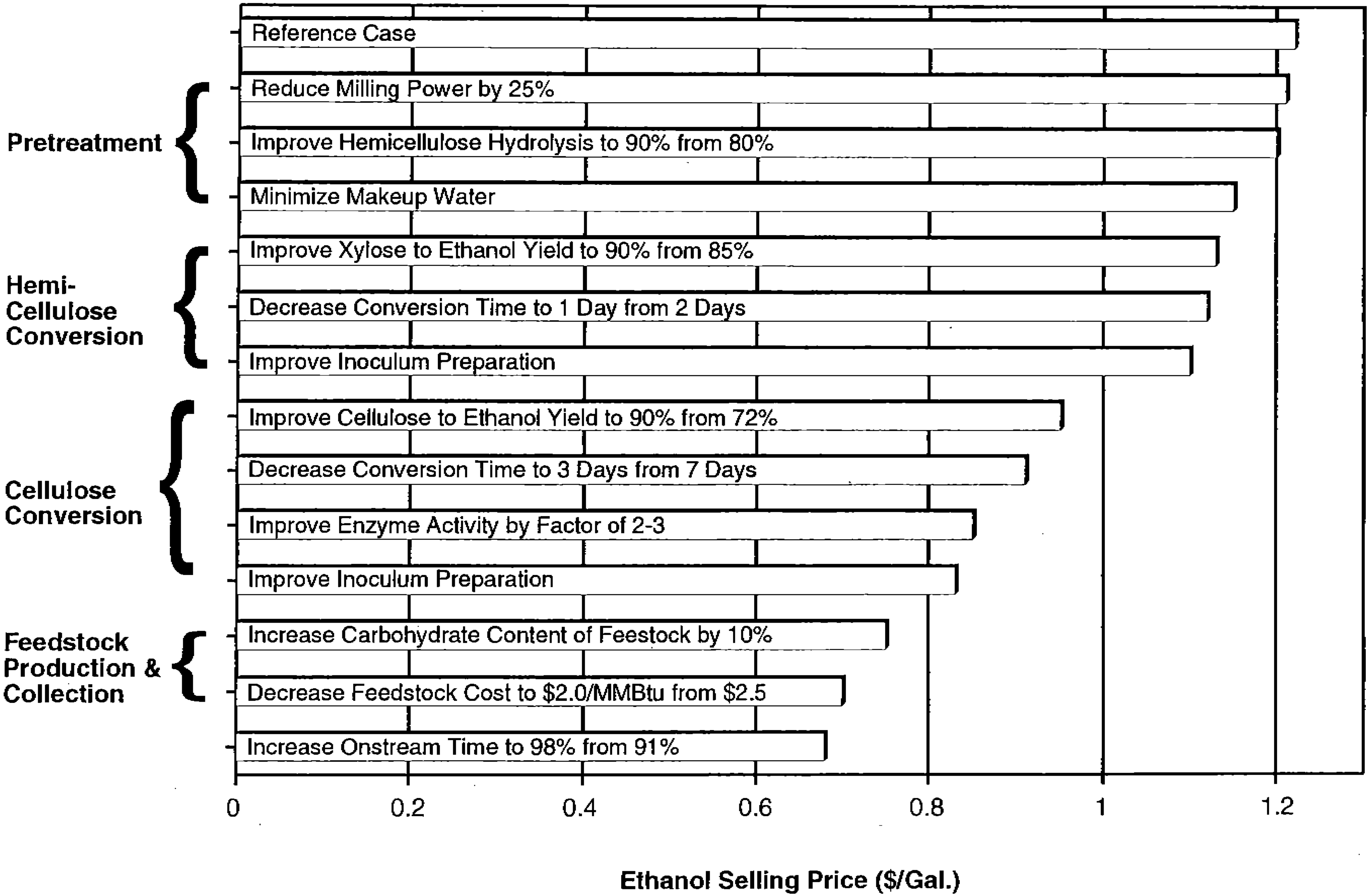
In order to work with industry to verify earlier biomass-to-ethanol bench-scale results, as well as meet the technological goals mentioned above, DOE's Biofuels Program through NREL, has established two cooperative research and development agreements (CRADAs)

Biomass-to-Ethanol Conversion

and one joint venture with industry. The first CRADA is with New Energy of Indiana. Located at an existing corn-to-ethanol facility, this CRADA will apply DOE-developed technology to increase yields from corn fiber feedstocks. Under this CRADA, a pilot plant is being constructed which will operate using process innovations in converting cellulose to ethanol, as well as investigating alternative methods of increasing the yield of ethanol from corn fiber. The economic analysis and recommendations stemming from this phase of the CRADA will be completed by June 1994. The second CRADA is with Amoco Oil Company. This CRADA is verifying the potential of waste paper as a low-cost feedstock for the biomass-to-ethanol conversion process. This CRADA has resulted in joint preliminary engineering studies and economic analyses. More detailed engineering studies are expected with additional laboratory tests. This CRADA will establish a process development unit (PDU) which will conduct several continuous flow experiments to optimize system design. These efforts will result in the development of a demonstrated, new, commercially-viable process by 1998. The last cooperative venture is with Interchem, a small company in Kansas City, that is scaling up the NREL vortex reactor for the ablative, fast pyrolysis of biomass and wastes to oils that can be converted into ethers for RFG. The fabrication of the scale-up vortex reactor has begun with the permitting process more than half-way complete.

If expected technological advances are realized, the reduction in cost of ethanol to $0.70/gallon will result in strong commercialization participation from the private sector. Given the success that the program has achieved in the past 12 years, it is expected that the necessary cost reductions can be achieved in the next 6-10 years. It should be noted that using biomass-ethanol as an ETBE blending component may result in earlier niche commercialization due to ETBE's high market value.

Exhibit 4
Goals of Ethanol From Cellulose Research



Biomass-to-Ethanol Conversion

Line 2. SYSTEM APPLICATION AND EXPECTED BENEFITS:

Developing a cost-effective source of biomass-based ethanol for liquid transportation fuels will help to improve the U.S. economy, environment, energy security, and process efficiency.

Economic benefits include the use of low-cost, renewable, biomass feedstocks such as AR, MSW, HEC, and SRWC. Creating a market for new cash crops will revitalize the U.S. farming industry. Feedstock processing and shipping brings new jobs to farming and logging equipment manufacturers, as well as those who harvest and transport feedstocks. The conversion of biomass to liquid biofuels creates domestic jobs for engineering and construction firms, biofuels refinery workers, and fuels handlers and shippers. The Biomass Power Program estimates that a biomass power industry can generate economic benefits of \$6.2 billion in personal and corporate income per year by 2010. The development of biomass power is expected to support 283,000 jobs annually by 2010.[2] Similar analyses for biomass-ethanol have not been completed, but comparable benefits are expected. Federal and state incentives programs will also make ethanol a viable fuel alternative to gasoline.

The use of MSW and other waste materials as a feedstock for conversion to liquid fuels reduces the demand for dwindling landfill space, while leading to productivity improvements since, some municipalities are paying as much as \$60-100/ton to dispose of waste. This also eases the demand for landfill space and lowers disposal costs.

Ethanol is more thermodynamically efficient than gasoline, providing a more complete combustion and fewer total emissions. As a direct additive and as a feedstock for ethyl-tertiary-butyl-ether (ETBE) used in reformulated gasoline (RFG), ethanol boosts the octane rating of the fuel blend and adds oxygen which lowers CO formation. The addition of ethanol also lowers the Reid Vapor Pressure (RVP), reducing evaporative emissions.

National energy security will be greatly enhanced by the widespread use of cost-effective ethanol, since the renewable feedstocks are domestically produced. Every quad of ethanol used displaces over 560,000 barrels/day of gasoline. If one assumes that it takes approximately 2 barrels of crude oil to produce 1 barrel of gasoline, a quad of ethanol displaces 1.1 million barrels of oil a day. Every 1% of oil displaced is accompanied by a 0.29% drop in the demand for electricity due to the excess electricity produced by the biomass-to-ethanol conversion process that is available to the grid.[3] The production of biomass-based ethanol will reduce U.S. dependency on foreign oil supplies.

The development of ethanol has increased process efficiencies by providing cost-competitive technology advances used in other industries, such as petroleum refining. Improvements in the genetic engineering, growth and harvesting of trees (such as the R&D conducted for SRWC) will also improve efficiencies in the lumber and pulp and paper products industries. Another benefit is the production of high-valued chemicals including ETBE and other ethers, higher alcohols and solvents, and pharmaceuticals. The use of ETBE will lead to improved process efficiencies for refiners, since they will be able to keep the low-cost gasoline fractions (such as butanes and benzenes), while meeting the Clean Air Act Amendment's RFG requirements.

Biomass-to-Ethanol Conversion

Line 3. TECHNICAL PERFORMANCE INDICATORS:

a. Scenario:

Indicator Name	Units	1995	2000	Future 2010	2020	2030
Overall Process Efficiency						
Ethanol Yield	%	72	72	81	87	90

b. Description, rationale, and assumptions:

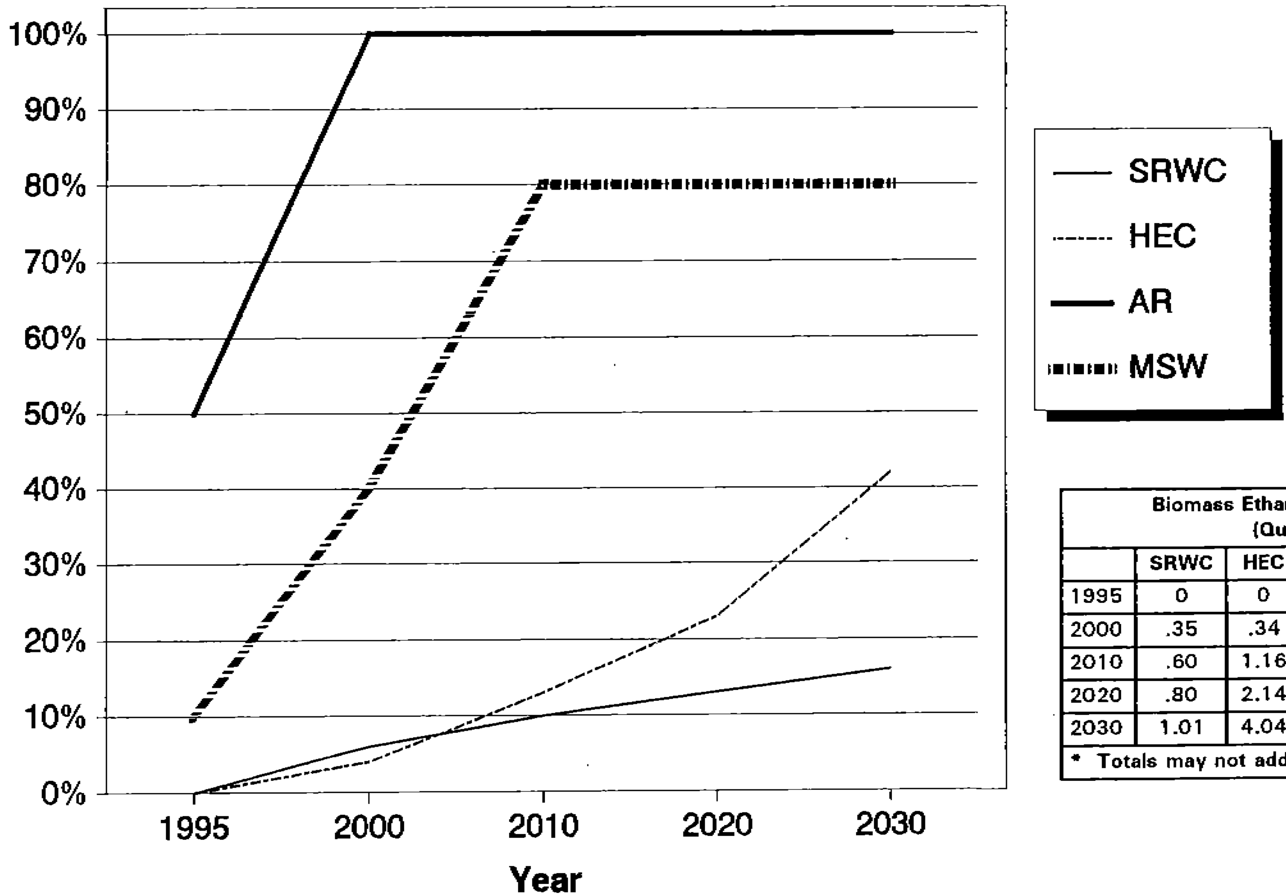
The base year for this technology characterization is 1995, when the biomass-to-ethanol conversion process may be commercially available. Detailed information starting from a 1990 base was not available. Below are the major rationale/assumptions that result in the detailed technical requirements information provided in Appendix A.

Biomass Feedstocks Assumptions Used in the Technology Characterization

In order to accurately present the available technologies for biomass conversion to ethanol, there are four feedstocks used in this characterization: agricultural residues, municipal solid waste, herbaceous energy crops and short rotation woody crops. In the characterization, each year depicted incorporates calculations based on the use of one feedstock as shown in Exhibit 5. Exhibit 5 illustrates the timing and percentage of total biomass resource base that is assumed for each biomass class. These overall assumptions will affect total production assumptions in Line 5.

Feedstocks that will be used in the short-term are agricultural residues and municipal solid waste. In 1995, the characterization is based on calculations using AR; in 2000, the feedstock used is MSW. This feedstock has two benefits: it will mitigate urban waste disposal problems due to severe landfill shortages currently being experienced which will become worse in the beginning of the next century; also, MSW will provide a low-cost feedstock for ethanol production. However, both of these short-term feedstocks have relatively limited overall resource bases compared to HEC and SRWC. Therefore, by the year 2010, the characterization assumes that energy crop production will provide the largest resource base for ethanol production, and that the predominant feedstock will be HEC. Calculations for the years 2010 and 2020, are based on HEC production figures. Finally, in 2030, the characterization bases its calculations on SRWC production figures. At this time, HEC will still be predominant, but SRWC are used to show the technical characteristics and costs of this feedstock. Even though SRWC have the longest establishment requirements, they are predicted to surpass all other feedstocks as a resource for ethanol production.[4]

Exhibit 5
Percentage of Biomass Class Resource Base Assumed Available for Ethanol Conversion



Biomass Ethanol Production (Quads)					
	SRWC	HEC	MSW	AR	TOTAL
1995	0	0	.06	.10	0.16
2000	.35	.34	.27	.19	1.16*
2010	.60	1.16	.64	.20	2.60
2020	.80	2.14	.74	.20	3.88
2030	1.01	4.04	.85	.20	6.10

* Totals may not add up due to rounding.

Source: Tshiteya, R. et al., *Assessment of Biomass Variability, Biomass Conversion, and Ethanol Use*, prepared for the U.S. Department of Energy, January, 1993.

Biomass-to-Ethanol Conversion

Since all four of these biomass classes will play an important biomass feedstock role, we have chosen a representative feedstock for each characterization year. It should be noted that information on the performance results of all four biomass class feedstocks are available for 2000 - 2030 but this information was left out due to space constraints.

Technology Improvement Assumptions

The overall process efficiency gains assumed above are the result of the expected technological improvements shown earlier in Exhibit 4. When these process efficiency gains in pretreatment, hemicellulose conversion, cellulose, and feedstock and collection are incorporated into the analysis, the result is an increase in overall ethanol yield conversion from 72 percent to 90 percent. For this technology characterization, it was assumed that almost no efficiency increases would occur between 1995 and 2000, when the biomass-to-ethanol conversion facilities are first introduced. However, by 2010, fifteen years after the first facilities are built, the largest increase in process efficiency is assumed due to system optimization, resulting in an overall efficiency of 81 percent. By 2020, the development of a new ethanol product recovery technology, the molecular sieve, is assumed to replace the earlier ethanol recovery method that utilized distillation. As a result of the molecular sieve, overall process efficiencies are increased to 87 percent. Finally, in 2030, it is assumed that slight modifications and process efficiencies have been achieved through optimization of the molecular sieve and other conversion processes which result in overall efficiency of 90%.

Each of the above process efficiency gains resulted in an increase in the expected capacity of the initial biomass-to-ethanol conversion facility. These increases in efficiencies and their impact on capital costs and per gallon costs are explained in the cost indicators section below.

Biomass-to-Ethanol Conversion

Line 4. COST INDICATORS

a. **Expected economic life (years):** 30

b. **Construction period (years):** 2

c. **Scenario:**

See Exhibit 6.

d. **Description, Rationale, and Assumptions:**

As mentioned earlier, this technology characterization limits the study to one biomass feedstock class per year: AR for 1995, MSW for 2000, HEC for 2010 and 2020, and finally SRWC for 2030. It is assumed that no significant change occurs between 1995 and 2000 when the biomass-to-ethanol conversion facilities are first introduced. Several assumptions were made with regard to plant capacity, capital recovery rate, initial production costs, capital increase/decrease rate, efficiency parameters, etc. Capital investment and cash costs are assumed to be equal in 1995 and 2000. However, these costs decrease from 2000 to 2030 due to increases in process efficiency. Capital recovery rate is assumed to equal 20%, which provides the annual capital charge for each feedstock and projection year. The 1993 Annual Energy Outlook inflation rate (3.9%) from the reference case is used for inflation/deflation purposes with all costs expressed in 1990 dollars. The capacity increases over the period 1995-2030. These increases in capacity are assumed to be a direct result of increases in conversion efficiency, and not at all due to changes in equipment and/or plant structure. As process efficiency increases, less steam is required, more electricity is produced than consumed, resulting in more electricity sold to the grid. Electricity and by-products costs are realized as benefits and thus appear as negative values in the cash cost section. These values increase in negativity reflecting the larger quantity of each commodity being sold to the utility grid. The incorporation of feedstock costs into the conversion facility model utilized specific regions and feedstock characteristics as follows: SRWC from PC, HEC from NC, AR from SE/SC, MSW from the national average. Feedstock costs are derived from S. Tyson's estimates of total production costs.[5] Where regional feedstock costs were not available, national averages were utilized. Where regional feedstock costs existed, straight arithmetic averages of landgroup categories of II and III were incorporated. The costs for AR and MSW were held constant over the model projection years, while the costs for SRWC and HEC decreased from $57.17 per ton to $40.33 and $77.37 to $52.53, respectively. All these calculations result in production costs decreasing over time from $2.40/gallon for AR in 2000 to $0.66/gallon for SRWC in 2030. Details of cost estimates are shown in Exhibits 6 and 7.

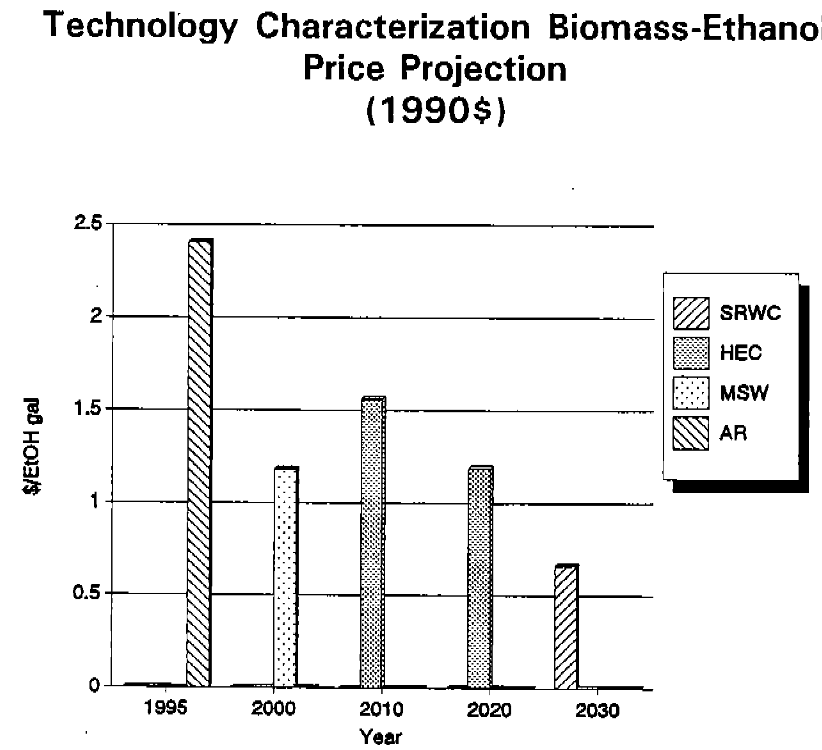
Exhibit 6
Cost Indicators

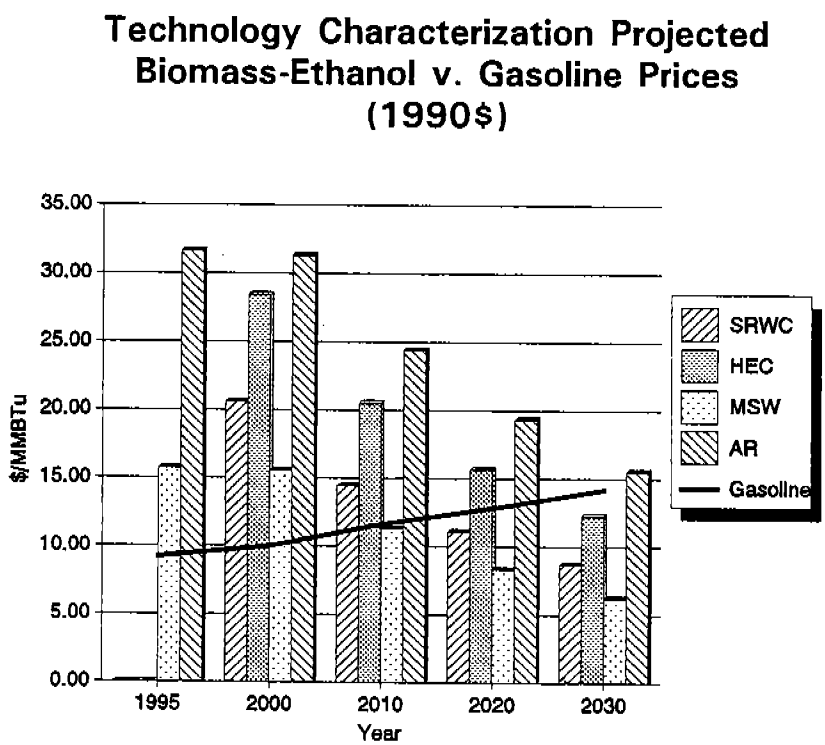
Feedstock Estimated Capital Investment	Units	AR Year 1995	MSW Year 2000	HEC Year 2010	HEC Year 2020	SRWC Year 2030
Capacity	tons/year	640,000	640,000	715,000	798,789	892,397
Throughput (National)	MM gal/year	1,259.58	3,524.66	15,274.11	28,186.38	13,258.84
Throughput (per plant)	MM gal/year	33.74	48.57	59.20	68.99	88.52
On Stream Time	hrs/year	8,000	8,000	8,000	8,000	8,000
Capital Cost Per Process Plant Area:	MM$					
Feedstock Handling		2.2800	2.2800	1.8240	1.4592	1.1674
Prehydrolysis		7.4200	7.4200	5.9360	4.7488	3.7990
Xylose Fermentation		1.9800	1.9800	1.5840	1.2672	1.0138
Cellulose Production		0.8600	0.8600	0.6880	0.5504	0.4403
SSF		7.1000	7.1000	5.6800	4.5440	3.6352
Ethanol Recovery		1.2400	1.2400	0.9920	0.7936	0.6349
Off-site Tankage		1.0000	1.0000	0.8000	0.6400	0.5120
Environmental Systems		1.3100	1.3100	1.0480	0.8384	0.6707
Utilities (except boiler)		10.6000	10.6000	8.4800	6.7840	5.4272
Miscellaneous		2.0300	2.0300	1.6240	1.2992	1.0394
Total Equipment Cost (except boiler)		35.8200	35.8200	28.6560	22.9248	18.3398
Times 2.85 Installation Factor		102.0870	102.0870	81.6696	65.3357	52.2685
Boiler Package		18.02	18.02	14.42	11.53	9.23
Fixed Capital Investment		120.1070	120.1070	96.0856	76.8685	61.4948
Miscellaneous		12.00	12.00	9.60	7.68	6.14
Start-up Costs		6.00	6.00	4.80	3.84	3.07
Working Capital		9.10	9.10	7.28	5.82	4.66
Total Capital Investment		147.21	147.21	117.77	94.21	75.37

Exhibit 6
Cost Indicators (Cont'd)

Feedstock **Estimated Capital Investment**	**Units**	**AR** **Year 1995**	**MSW** **Year 2000**	**HEC** **Year 2010**	**HEC** **Year 2020**	**SRWC** **Year 2030**
Components:	MM$/Yr					
Feedstock		36.84	10.75	57.29	54.48	40.33
Materials		7.74	7.74	6.19	4.95	3.96
Gypsum Disposal		0.4	0.4	0.32	0.26	0.20
Electricity		(5.32)	(3.22)	(4.72)	(4.22)	(7.05)
Water		0.12	0.12	0.10	0.08	0.06
Labor/Supervision		1.57	1.57	1.26	1.00	0.80
Maintenance		4.14	4.14	3.31	2.65	2.12
Direct Overhead		0.71	0.71	0.57	0.45	0.36
General Overhead		3.71	3.71	2.97	2.37	1.90
Insurance, Property Tax		2.07	2.07	1.66	1.32	1.06
By-Products Credits		(0.28)	(0.37)	(0.22)	(0.20)	(0.29)
Total Cash Cost		51.69	27.99	68.72	63.16	43.47
Annual Capital Charge		29.44	29.44	23.55	18.84	15.07
Total Cost of Production		81.13	57.43	92.27	82.00	58.54
Ethanol Cost	$/gal	2.40	1.18	1.56	1.19	0.66
Source: Meridian Corporation, *Biomass-to-Ethanol Performance Model*, April 29, 1993						

Exhibit 7





* Motor gasoline based on *EIA's 1993 Annual Energy Outlook* - Reference Case.

Biomass-to-Ethanol Conversion

Line 5. MARKET INDICATORS

a. **Scenario:** Based on a 1992 Biomass-to-Ethanol Feedstock Model run that provides total resource base information as well as market penetration assumptions and resource utilization for the four biomass class feedstocks as illustrated in Exhibit 5.[6]

Exhibit 8
MARKET INDICATORS

Quads	**1995**	**2000**	**2010**	**2020**	**2030**
Biomass Resource Base	15.02	15.20	15.77	16.42	16.97
Maximum Technical	.16	1.16	2.60	3.88	6.10
Ethanol Market Potential					
-LDV & Freight Trucks	17.55	18.96	20.62	22.98	25.64
Percentage of Potential Market					
Biomass Resource Base					
-LDV & Freight Truck	85.6%	80.2%	76.5%	71.5%	66.2%
Maximum Technical					
-LDV & Freight	.9%	6.1%	12.6%	16.6%	23.8%

Sources: Annual Energy Outlook (AEO) 1993, p. 96.
Note: Assumed same rates of annual increases used in AEO for 1990-2010 for out year projections of 2010-2030.

b. **Description, rationale, and assumptions:**

The biomass-to-ethanol information presented above is based on the following assumptions. The first is that the technology is commercially available by 1995. As is mentioned below, the market size for oxygenates is more than the amount of biomass-ethanol projected to be produced in 1995. For the year 2000, biomass-ethanol can provide double the amount required by the oexygenate market. Based on EIA's *1993 Annual Energy Outlook*, the projected demand for transportation fuels in the light-duty vehicle (LDV) and freight truck markets exceeds the assumed ethanol production as shown in Exhibit 8. As Exhibit 8 above illustrates, depending if and when the full U.S. biomass resource base assumed in the scenario could be put into production, ethanol could supply over 85% of the LDV and freight truck market in 1995 declining to 66% by 2030 due expected increases in travel demand. Based on the model run used in this analysis (which is being characterized as the maximum technical), ethanol could contribute anywhere between .9% up to 24% of the LDV and freight truck market between 1995 and 2030. It must be noted that the maximum technical scenario presented is a preliminary run. Additional model runs and scenarios need to be developed. However, given market, regulatory and policy climate requirements, it would not be unrealistic to expect an accelerated development of full ethanol production capacity utilizing the total biomass resource base presented.

c. **Market Analysis and Deployment Issues:**

The transportation sector, particularly LDV and freight trucks, provides the best market for biomass ethanol. In the last several years, the demand for ethanol from this fleet has been roughly one billion gallons. This demand is expected to increase to 4.1 billion gallons by 1995 due to Clean Air Act oxy-fuel and reformulated gasoline programs. Ethanol will primarily be used as an oxygenate for gasoline. According to the maximum technical scenario presented above, biomass-ethanol could provide 50% of the oxygenate demand. By 2000, the oxygenate demand will increase to 6.2 billion gallons.[7] Based on the maximum technical projection of 15.2 billion gallons (1.16 quads), biomass-ethanol could supply 100% of the oxygenate market, while providing an additional 11 billion ethanol gallons of neat fuel for a growing flexible and dedicated ethanol fleet. As Exhibit 8 shows, by 2030, biomass-ethanol could provide 24% of the fleet requirement. At this point, vehicles will be primarily using ethanol in dedicated systems, as opposed to an oxygenate for gasoline.[8]

Several issues affect the marketing of ethanol: capital costs, location, non-rationalized industry participants and risk perceptions. The industry will face high capital costs due to land requirements and specialized equipment requirements. The most influential factors are the level of demand and establishment of infrastructure. Current costs are high since the use of pipelines is not an available option, due to low volumes, phase separation, and solvent characteristics of alcohols. The most widely used mode is trucking, which can be up to 10 times more costly than pipeline shipments. The ethanol industry will be dependent on the location of the feedstock sources, i.e., the north central region of the United States. Except for a few markets, however, this places the industry far from the high-value markets of the northeast, Pacific coast and southwest. The ethanol industry must gain access to the most efficient and least costly transport method: pipelines.

The industry currently suffers from a lack of clear, strong market leaders. Some likely industries, such as pulp/paper, agricultural and forestry, have avoided involvement. The oil companies still view ethanol as a competitor rather than a resource. The corn/grain-to-ethanol industry has been involved in a limited way. The lack of leadership has led to inefficient marketing. The ethanol R&D program will need to disseminate information on new technologies and attempt to involve potential industry participants. It must develop innovative transactional models to overcome the "chicken/egg" dilemma and to avoid exaggerated perceptions of risk and resulting high required rates of return. Any new industry will be deemed risky by definition and will require higher returns. This is exacerbated by the trend of short payback schedules. Capital costs must be lowered in order for ethanol to compete. Current efforts are focusing on lowering feedstock costs, lowering transport/distribution costs, maintaining production levels at

Biomass-to-Ethanol Conversion

capacity, as well as alternative methods, such as investment pooling. These efforts seek to lower perceived risks and lower required rates of return. [9]

Line 6. EFFLUENTS

a. **Scenario:**

Indicator Name	Units	Base Year 1995	Future 2000	2010	2020	2030
- AIR RELEASES	tons/year					
. CO2		635,725	844,606	1,089,444	1,269,491	1,919,74
. CO		280	326	443.7	517	988
. SO2		45.5	136.4	123.1	143.4	356.4
. NOx		157	180	276.5	322.2	538.3
. PM-10		91.3	422	150.5	175.4	290.5
. Pb		0.0	0.022680	0.0	0.0	0.0
. HCl		0.0	64	0.0	0.0	0.0
. VOC - Total		46.9	54.64	75.85	88.41	165.5
. Gasoline		0.67	.97	42.2	1.38	1.77
. Diesel		0.00198	0.00217	1.18	0.00309	0.00493
. Ethanol		4.7	6.2	0.00265	10.1	13.4
. Acetaldehyde		0.615	.828	1.079	1.261	2.152
. Formaldehyde		0.410	.542	.722	.834	1.399
. Ammonia		27.1	34.2	44.6	52	89.4
- WATER RELEASES	tons/year					
. Suspended solids		370	559	574	669	1,231
. Oil & Grease*		nil	nil	nil	nil	nil
. COD		444	671	688	802	1,476
. Thermal		n/a	n/a	n/a	n/a	n/a
- LAND CONCERNS	acres					
. Land area		50	50	50	50	50

* The amount of these releases is insignificant.

b. **Description, rationale, and assumptions:**

During the conversion process, each conversion step becomes an environmental concern. The table above shows the tonnage of various emissions released to the air, water, and the land by the processing of different feedstocks at a 50 million gallon per year biomass-to-ethanol facility. The figures are totals of emissions from the mashing, fermentation and distillation and waste disposal stages, as well as from the plant boilers and from vehicles used for transportation of feedstocks **within** the plant. Emissions from the production and harvesting of the feedstocks are not considered. (See Assessment of Biomass Variability, Biomass Conversion, and Ethanol Use for information on these emissions.)[10]

Biomass-to-Ethanol Conversion

Line 7. DIRECT RESOURCE REQUIREMENTS

a. **Scenario: See Exhibit 9**

b. **Description, rationale, and assumptions:**

The most important input required for the conversion facility is the biomass feedstock itself. For the first year (1995), the conversion plant design is based on a feedstock rate of 160,000 lb/hr per year. The feedstock rate increases over the years and reaches 223,100 lb/hr per year in 2030.

In addition to the feedstock, chemicals and enzymes are required for the conversion process steps to run smoothly. Some of these chemicals directly participate in the main reaction. This is the case for sulfuric acid, which is needed for the prehydrolysis, and the lime used in the neutralization step following prehydrolysis. In this step, the lime reacts with the sulfuric acid to neutralize the material from the prehydrolysis reactor, prior to fermentation. Other chemicals, such as nutrients, corn steep (CS) liquor, ammonia, etc., are used as a source of nutrients for microorganisms.

Several chemicals are required to treat boiler feedwater before it can be fed to the high pressure boiler. Chemicals used to treat cooling water include inhibitors to prevent scale formation on heat exchanger surfaces and a biocide to prevent buildup of algae and other types of microorganisms in the circulating cooling water. Several types of nutrients are also used as chemicals for the microorganisms in the waste water treatment system.

Low-sulfur diesel fuel is used by equipment such as front-end loaders and tractors, which are used in the feedstock handling area to move the feedstock from the storage piles to conveyors. Some additional assumptions could be made regarding the use of ethanol itself to power this equipment, instead of diesel. Such assumptions have not been incorporated into this characterization. Gasoline is required to denature the ethanol product.

The model compares the required utilities for different feedstocks from 1995 through 2030. The utilities included account for the efficiency of the boiler/turbo-generator; the electricity produced, consumed and sold to the grid; the steam requirement; the plant requirement for cooling water, chilled water, and process air. The process produces more electricity than needed to run the plant, resulting in a surplus that could be sold to the grid.[11]

Exhibit 9
Direct Resource Requirements

INDICATOR NAME	BASE YEAR		FUTURE							
	1995		2000		2010		2020		2030	
	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required
LAND*	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
WATER										
10^8 gal/yr	0.000009	5.8	0.000010	6.53	0.000009	6.35	0.000009	7.09	0.000013	11.45
ENERGY										
Utilities:										
Efficiency of Boiler/ Turbo Generator		76%		69%		74%		74%		77%
Plant Electricity Consumed	0.000017	11.1	0.000017	10.8	0.000015	10.4	0.000015	11.6	0.000023	20.5
Plant Steam Requirement (lb/hr)										
50 psig	0.237762	152,168	0.223776	143,217	0.223776	160,000	0.223776	178,750	0.297902	265,847
150 psig	0.110070	70,445	0.060280	38,579	0.099860	71,400	0.099860	79,767	0.094825	84,622
Plant Cooling Water Requirement (GPM)	0.057483	36,789	0.062937	40,280	0.053147	38,000	0.053147	42,453	0.083077	74,138
Plant Chilled Water Requirement (GPM)										
3.6 °F delta T	0.000773	495	0.001275	816	0.000684	489	0.000684	546	0.001052	939
27 °F delta T	0.000584	374	0.000963	616	0.000516	369	0.000516	412	0.000794	709
Plant Process Air Requirement (lb/hr)	0.023776	15,217	0.033147	21,214	0.021259	15,200	0.021259	16,981	0.030769	27,458

Exhibit 9
Direct Resource Requirements (Cont'd)

INDICATOR NAME	BASE YEAR		FUTURE							
	1995		2000		2010		2020		2030	
	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required
FUELS										
Gasoline (5% of the ethanol produced per plant)		1,687,020		2,428,421		2,960,161		3,449,374		4,426,186
Diesel	0.306294	196,028	0.152448	97,566	0.152448	109,000	0.152448	121,773	0.272727	243,381
FEEDSTOCKS										
Dry Biomass** (Total Tons Required)	ARs	640,000	MSW	640,000	HECs	715,000	HECs	798,789	SRWCs	892,397
CHEMICALS										
Limestone	0.002084	1,334	0.002573	1,647	0.003203	2,290	0.003203	2,558	0.001161	1,036
Sulfuric Acid	0.017343	11,099	0.017343	11,099	0.017203	12,300	0.017203	13,741	0.017203	15,352
Lime	0.012783	8,181	0.012783	8,181	0.012699	9,080	0.012699	10,144	0.012671	11,308
Ammonia	0.041916	26,826	0.013692	8,763	0.042643	30,490	0.042643	34,063	0.027580	24,613
CS Liquor	0.001081	692	0.001916	1,226	0.000937	670	0.000937	749	0.001483	1,323
Nutrients	0.000312	200	0.000552	354	0.000270	193	0.000270	216	0.000427	381
Antifoam	0.000066	42	0.000120	77	0.000060	43	0.000060	48	0.000090	80
BFW Chemicals										
Na2PO4	0.000001	0.54	0.000001	0.40	0.000001	0.51	0.000001	0.57	0.000001	1.04
Amine	0.000003	1.61	0.000002	1.20	0.00002	1.52	0.000002	1.70	0.000003	3.11
Hydrazine	0.000008	5.36	0.000006	4.01	0.000007	5.06	0.000007	5.65	0.000012	10.36

Exhibit 9
Direct Resource Requirements (Cont'd)

INDICATOR NAME	BASE YEAR		FUTURE							
	1995		2000		2010		2020		2030	
	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required	Required Amount/ Ton Processed	Total Tons Required
CW Chemicals										
Silicate	0.000005	3.16	0.000005	3.46	0.000005	3.26	0.000005	3.64	0.000007	6.37
Phosphonate	0.000002	1.18	0.000002	1.30	0.000002	1.22	0.000002	1.36	0.000003	2.38
Polyphosphate	0.000006	3.95	0.000007	4.33	0.000006	4.08	0.000006	4.56	0.000009	7.96
Orthophosphate	0.000006	3.95	0.000007	4.33	0.000006	4.08	0.000006	4.56	0.000009	7.96
Zinc	0.000003	1.98	0.000003	2.17	0.000003	2.04	0.000003	2.28	0.000004	3.98
WWT Chemicals										
Urea	0.001860	1,190	0.000923	591	0.002098	1,500	0.002098	1,676	0.001105	986
Triple Super Phosphate	0.000000	0.0	0.000378	242	0.000825	590	0.000825	659	0.000420	374
Polymer	0.000727	465.5	0.000008	5.1		0.0		0.0		0.0
LABOR										
Labor Input (employees)										
Supervisors	0.000014	9	0.000014	9	0.000014	10	0.000014	11	0.000014	12
Operators	0.000057	37	0.000057	37	0.000057	41	0.000057	46	0.000057	51
Maintenance	0.000056	36	0.000056	36	0.000056	40	0.000056	45	0.000056	50

Assessment of Biomass Variability, Biomass Conversion, and Ethanol Use pp.II-3,4 and Appendix B.

* A 50 million gallon per year ethanol plant requires roughly 69 acres. This figure is not expected to change much in the future. (Walter W. Klein, Senior Vice President, Raphael Katzen Associates).

** Calculations throughout the table are based on different feedstocks for each year presented. In 1995, the feedstock used is agricultural residues; in 2000, municipal solid waste; in 2010 and 2020, herbaceous energy crops; in 2030, short rotation woody crops.

Biomass-to-Ethanol Conversion

Line 8. REFERENCES

1. National Renewable Energy Laboratory et al., *A Comparative Analysis of the Environmental Outputs of Future Biomass-Ethanol Production Cycles and Crude Oil/Reformulated Gasoline Production Cycles,* DRAFT, December 1991.

2. *Biofuels Program Evaluation Briefing Book*, DRAFT. Prepared for U.S. Department of Energy by Meridian Corporation. March 1993. Section 2-1.

3. Stone, K., and Lynd, Lee, *Analysis of Internal and External Energy Flows Associated with Projected Process Improvements in Biomass Ethanol Production*, presented in the Proceedings of the DOE Automotive Technology Contraction's Coordination Meeting, Detroit, MI, 1993.

4. Tshiteya, Rene, et. al. *Assessment of Biomass Variability, Biomass Conversion, and Ethanol Use.* Prepared for U.S. Department of Energy by Meridian Corporation. January 1993. pp. ii and I-17.

5. Tyson, S., *Biomass Resource Potential of the United States,* DRAFT, prepared for U.S. Department of Energy, October 1990.

6. Tshiteya, et. al., *Assessment* op. cit.

7. Pace Petrochemical Service, *1991 Annual Issue.*

8. U.S. Department of Energy, *Annual Energy Outlook 1993*, p. 96

9. *Biofuels Program Evaluation Briefing Book, DRAFT.* op. cit. Section 4-3.

10. Tshiteya, et. al. *Assessment* op. cit. pp. II-11, 14, 15.

11. Ibid. pp. II-3.

Appendix A

Technical Performance Indicators

Technical Performance Indicators
Biomass-to-Ethanol Conversion Facility
Parameters and Assumed Efficiency
Increases (Annual Basis)

Process/Stage Equipment		1995 AR		2000 MSW	
	Units	Efficiency/ Levelized Factors	Output	Efficiency/ Levelized Factors	Output
Prehydolysis/Neutralization:					
Temperature	°C		160		160
Residence Time	minutes		10		10
Hemicellulose-to-Xylose (lb/hr)	%	80.0%	3,126	80.0%	10,880
Hemicellulose-to-Furfural (lb/hr)	%	13.0%	508	13.0%	1,768
Cellulose-to-Unconverted (lb/hr)	%	7.0%	274	7.0%	952
Cellulose-to-Glucose (lb/hr)	%	3.0%	1,664	3.0%	408
Cellulose-to-HMF (lb/hr)	%	0.1%	55	0.1%	14
Cellulose-to-Unconverted (lb/hr)	%	96.9%	53,760	96.9%	13,178
Xylose Conversion:					
Xylose Available (lb/hr)	%	95%	2,970	95%	10,336
Xylose Converted (lb/hr)	%	90%	2,673	90%	9,302
Fermentation Time	days		2		2
pH			7.0		7.0
Temperature	°C		37		37

Note: Bold numbers indicate assumed process efficiency from current bench-scale results.

Technical Performance Indicators
Biomass-to-Ethanol Conversion Facility
Parameters and Assumed Efficiency
Increases (Annual Basis)

Process/Stage Equipment		1995 AR		2000 MSW	
	Units	Efficiency/ Levelized Factors	Output	Efficiency/ Levelized Factors	Output
Cellulase Production:					
Cellulose use for Cellulase Production	lb/hr	2%	1,110	2%	1,456
Method of Operation			Batch		Batch
Temperature	°C		28		28
Pressure	psig		10		10
Fermentation Time	days		5.5		5.5
Cellulase Yield	IU/g cellulose		101,669,413		133,409,203
SSF-Process:					
Temperature	°C		37		37
Residence Time	days		7		7
Cellulose Converted to:					
Ethanol (lb/hr)	%	72.0%	39,147	72.0%	51,368
Fusel Oil (lb/hr)	%	0.1%	54	0.1%	71

Note: Bold numbers indicate assumed process efficiency from current bench-scale results.

Technical Performance Indicators
Biomass-to-Ethanol Conversion Facility
Parameters and Assumed Efficiency
Increases (Annual Basis)

Process/Stage Equipment		1995 AR		2000 MSW	
	Units	Efficiency/ Levelized Factors	Output	Efficiency/ Levelized Factors	Output
Glycerol/Acetaldehyde (lb/hr)	%	4.9%	2,664	4.9%	3,496
Cells (lb/hr)	%	10.0%	5,437	10.0%	7,134
Cellulose Unconverted (lb/hr)	%	13.0%	7,068	13.0%	9,275
Ethanol Recovery:					
Recovery Process			Trad Dist		Trad Dist
Dehydration Process			Azeot Dist		Azeot Dist
Ethanol Recovery	%		95.0%		**96.0%**
Steam Requirement	lb/gal EtOH		25.8		25.8
Waste Treatment:					
Conv of Soluble Solids to Biogas (lb/hr)	%	90%	70,587	90%	3,600
Conversion of Xylose to biogas (lb/hr)	%	90%	297	90%	1,034
Conversion of Furfural to Biogas (lb/hr)	%	90%	457	90%	1,591
Conversion of Glycerol to Biogas (lb/hr)	%	90%	2,447	90%	3,210

Note: Bold numbers indicate assumed process efficiency from current bench-scale results.

Technical Performance Indicators
Biomass-to-Ethanol Conversion Facility
Parameters and Assumed Efficiency
Increases (Annual Basis)

Process/Stage Equipment		1995 AR		2000 MSW	
	Units	Efficiency/ Levelized Factors	Output	Efficiency/ Levelized Factors	Output
Utilities:					
Efficiency of Boiler/Turbo Generator	%		76%		69%
Plant Electricity Produced	KW	0.000037	23.5	0.000029	18.3%
Plant Electricity Consumed	KW	0.000017	11.1	0.000017	10.8
Plant Electricity Sold	KW	0.000019	12.4	0.000012	7.5
Plant Steam Requirement:					
50 psig	lb/hr	0.237762	152,168	0.223776	143,217
150 psig	lb/hr	0.110070	70,445	0.060280	38,579
Plant Cooling Water Requirement	GPM	0.057483	36,789	0.062937	40,280
Plant Chilled Water Requirement					
3.6° F delta T	GPM	0.000773	495	0.001275	816
27° F delta T	GPM	0.000584	374	0.000963	616
Plant Process Air Requirement	lb/hr	0.023776	15,217	0.033147	21,214

Note: Bold numbers indicate assumed process efficiency from current bench-scale results.

Technical Performance Indicators
Biomass-to-Ethanol Conversion Facility
Parameters and Assumed Efficiency
Increases (Annual Basis)

		2010 HEC		2020 HEC		2030 SRWC	
Process/Stage Equipment	Units	Factors		Factors		Factors	
Prehydolysis/Neutralization:							
Temperature	°C		160		160		160
Residence Time	minutes		10		10		10
Hemicellulose-to-Xylose (lb/hr)	%	**83.0%**	47,139	**87.0%**	55,202	**90.0%**	37,712
Hemicellulose-to-Furfural (lb/hr)	%	**12.0%**	6,815	**11.0%**	6,980	**10.0%**	4,190
Cellulose-to-Unconverted (lb/hr)	%	**5.0%**	2,840	**2.0%**	1,269	**0.0%**	0
Cellulose-to-Glucose (lb/hr)	%	**3.0%**	1,704	**3.0%**	1,904	3.0%	1,257
Cellulose-to-HMF (lb/hr)	%	0.1%	57	0.1%	63	0.1%	42
Cellulose-to-Unconverted (lb/hr)	%	96.9%	55,034	96.9%	61,483	96.9%	40,604
Xylose Conversion:							
Xylose Available (lb/hr)	%	**97%**	45,725	**99%**	54,650	**100%**	37,712
Xylose Converted (lb/hr)	%	**93%**	42,525	**94%**	51,371	**95%**	35,827
Fermentation Time	days		2		2		2
pH			7.0		7.0		7.0
Temperature	°C		37		37		37

Note: Bold numbers indicate assumed process efficiency from current bench-scale results.

**Technical Performance Indicators
Biomass-to-Ethanol Conversion Facility
Parameters and Assumed Efficiency
Increases (Annual Basis)**

		2010 HEC		2020 HEC		2030 SRWC	
Process/Stage Equipment	Units	Factors		Factors		Factors	
Cellulase Production:							
Cellulose use for Cellulase Production	lb/hr	2%	1,078	2%	1,204	2%	2,177
Method of Operation			Batch		Batch		Batch
Temperature	°C		28		28		28
Pressure	psig		10		10		10
Fermentation Time	days		5.5		5.5		5.5
Cellulase Yield	IU/g cellulose		142,270,167		208,099,911		464,024,468
SSF-Process:							
Temperature	°C		37		37		37
Residence Time	days		7		7		7
Cellulose Converted to:							
Ethanol (lb/hr)	%	**81.0%**	42,779	**87.0%**	51,332	**90.0%**	95,986
Fusel Oil (lb/hr)	%	0.1%	53	0.1%	59	0.1%	107
Glycerol/Acetaldehyde (lb/hr)	%	4.9%	2,588	4.9%	2,891	4.9%	5,226
Cells (lb/hr)	%	**8.0%**	4,225	**6.0%**	3,540	5.0%	5,333

Note: Bold numbers indicate assumed process efficiency from current bench-scale results.

Technical Performance Indicators
Biomass-to-Ethanol Conversion Facility
Parameters and Assumed Efficiency
Increases (Annual Basis)

		2010 HEC		2020 HEC		2030 SRWC	
Process/Stage Equipment	Units	Factors		Factors		Factors	
Cellulose Unconverted (lb/hr)	%	**6.0%**	3,169	**2.0%**	1,180	**0.0%**	0
Ethanol Recovery:							
Recovery Process			**Integr Dist**		**Integr Dist**		**Integr Dist**
Dehydration Process			**Mole Siev**		**Mole Siev**		**Mole Siev**
Ethanol Recovery	%		**97.0%**		**98.0%**		**99.0%**
Steam Requirement	lb/gal EtOH		**16.5**		16.5		16.5
Waste Treatment:							
Conv of Soluble Solids to Biogas (lb/hr)	%	90%	21,289	90%	23,784	90%	0
Process/Stage Equipment:							
Conversion of Xylose to Biogas (lb/hr)	%	90%	4,573	90%	5,465	90%	3,771
Conversion of Furfural to Biogas (lb/hr)	%	90%	6,134	90%	6,282	90%	3,771

Note: Bold numbers indicate assumed process efficiency from current bench-scale results.

Technical Performance Indicators
Biomass-to-Ethanol Conversion Facility
Parameters and Assumed Efficiency
Increases (Annual Basis)

		2010 HEC		2020 HEC		2030 SRWC	
Process/Stage Equipment	Units	Factors		Factors		Factors	
Conversion of Glycerol to Biogas (lb/hr)	%	90%	2,377	90%	2,655	90%	4,799
Utilities:							
Efficiency of Boiler/Turbo Generator	%		74%		74%		77%
Plant Electricity Produced	KW	0.000034	24.1	0.000034	26.9	0.000059	52.5
Plant Electricity Consumed	KW	0.000015	10.4	0.000015	11.6	0.000023	20.5
Plant Electricity Sold	KW	0.000019	13.7	0.000019	15.3	0.000036	32.1
Plant Steam Requirement:							
50 psig	lb/hr	0.223776	160,000	0.223776	178,750	0.297902	265,847
150 psig	lb/hr	0.099860	71,400	0.099860	79,767	0.094825	84,622
Plant Cooling Water Requirement	GPM	0.000019	38,000	0.053147	42,453	0.083077	74,138
Plant Chilled Water Requirement							
3.6° F delta T	GPM	0.000684	489	0.000684	546	0.001052	939
27° F delta T	GPM	0.000516	369	0.000516	412	0.000794	709
Plant Process Air Requirement	lb/hr	0.021259	15,200	0.021259	16,981	0.030769	27,458

Note: Bold numbers indicate assumed process efficiency from current bench-scale results.